Triboelectric Testing at KSC Under Low Pressure and Temperature

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Abstract **-** The purpose of this study at Kennedy Space Center (KSC) was to develop and test a second-generation triboelectric robot capable of operating in a special vacuum chamber. The robot tested PTFE and four thin films under low pressures down to 0.6 torr. An anti-static polyethylene was tested at several temperatures. This report shows the effects of low pressures and temperature on these films. The Paschen curve was also measured for polytetrafluoroethylene (PTFE). This report also shows the influence of the Paschen effects on the four triboelectrically charged insulating films and PTFE. Data from the robot testing shows the Paschen voltages for insulators can be significantly higher than that for a conductor. The report recommends that materials used in critical space applications and planetary applications be electrostatically tested at low pressure, low temperature and/or hard vacuum prior to use.

I. Introduction

Successful testing of materials for charge generation and decay has been performed at the Kennedy Space Center (KSC) Electromagnetic Physics Laboratory (EMPL) since 1963. During this period the effects of relative humidity on the triboelectric properties of thousands of materials have been evaluated and the reports published by the Materials Science Laboratory at KSC (for example: Gompf, MTB-402-85). A triboelectric test robot (figure 1) has been designed that now makes it possible to identify the effects of not just humidity but completes the picture by including the effects of temperature, low pressure and a variety of gases that can simulate other planetary atmospheres. The results obtained can be applicable to orbital, lunar or planetary environments. For example, the Martian environment's temperature, pressure and gas composition can be duplicated. Conditioning and triboelectric testing can be done under those conditions. This report also shows the measured effect that the Paschen curve has on the electrostatic performance of a material under a variety of low pressures.

Figure 1. ESD Robot

II. History

This first serious electrostatic accident occured at the Kennedy Space Center in 1963. At that time there were no widely recognized testing methods used that would completely identify the electrostatic properties of a material. It was in this environment that the first KSC Triboelectric device was developed. While this device was crude in design, it did provide a start toward electrostatic testing of materials in order to select the safest material for use. The next 20 years saw many improvements in this device especially in the controlling of the test parameters. This author made many changes to the original device such as controlling the rubbing time, the acclimation time at constant environmental conditions, the test pressure, the humidity, the temperature, sample size, test pressure and the use of the latest electronic devices to accurately read and record data. This first successful device was reported in the 1984 EOS/ESD Symposium Proceedings (Gompf 1984). This device, still in use today, has been used by the author to test thousands of materials (Gompf, MTB-402-85). The device described by this report is the third (second robotic device) in the series of triboelectric devices at KSC.

III. Robot Design and Operation

The first ESD Robot used at KSC was conceived by this author and reported in the EOS/ESD Symposium Proceedings (Gompf 1986). The ESD Robot used in this study is a newly designed one that was conceived by the author and was designed to be operated under a wide variety of environmental conditions including at vacuum, low pressure, and high or low temperatures. It was developed to enable material samples to be tested in a variety of environmental chambers, primarily thermal-vacuum chambers where the cycle times for vacuum and temperature are such that testing single samples is inefficient.

The robot design and operation is similar to both the first KSC triboelectric device and the first robotic device. This design permits a continuity in the test results such that they are compatible to each other and can be compared on a common basis. All three devices use the same 5 inch diameter rubbing wheel with a felt PTFE rubbing surface backed with 1 inch of soft foam. This rubbing wheel rotates at precisely 200 rpm and rubs the sample for 10 seconds at a pressure of 3 pounds. After rubbing the sample it is transported within 0.2 seconds to the front of the electrostatic detector for surface voltage monitoring and recording. The robot has storage for 6 samples to be stored and remotely selected for testing. The detection system has capability for automatic self grounding every 5 seconds for long duration tests or can be operated in a continual open position for test of short duration. The data is displayed and stored on a digital oscillograph prior to transfer to a computer for analysis.

IV. Paschen Curve Effects

The Paschen Curve identifies the maximum voltage obtainable between two surfaces under controlled pressure conditions. For the same geometric shape, as the pressure is lowered from 1 atmosphere, the maximum voltage obtainable decreases to a minimum value and then increases as the pressure is lowered further. This author wondered how this would affect the voltage retention and generating ability of an insulating material. For the same geometry, would the generating capacity of an insulating film be reduced to the Paschen voltage of a conductor or would the insulating material have its own Paschen voltage that may be significantly higher than that of a conductor? No clear answers to this problem have been given in our discussions with workers in the field.

The figure 2 graph is the measured Paschen curve for PTFE. It was obtained by using the robot to tribocharge the PTFE plate sample with the soft foam backed PTFE felt rubbing wheel to 17860 volts. The PTFE plate voltage and the chamber pressure were recorded on a digital storage oscilloscope. The pressure in the chamber was then slowly lowered from 760 torr to 0.8 torr over a 25 minute time period. It is to be noted from figure 3 that the reduction of surface voltage due to Paschen effects was not a smooth curve such as that for a metal conductor but rather consisted of several sudden precipitous drops in voltage. The largest of several of these sudden changes occured at 157 seconds into the test at a pressure of 300 Torr. At this time there was a sudden change (an arc?) from -12380 volts to -7280 volts.

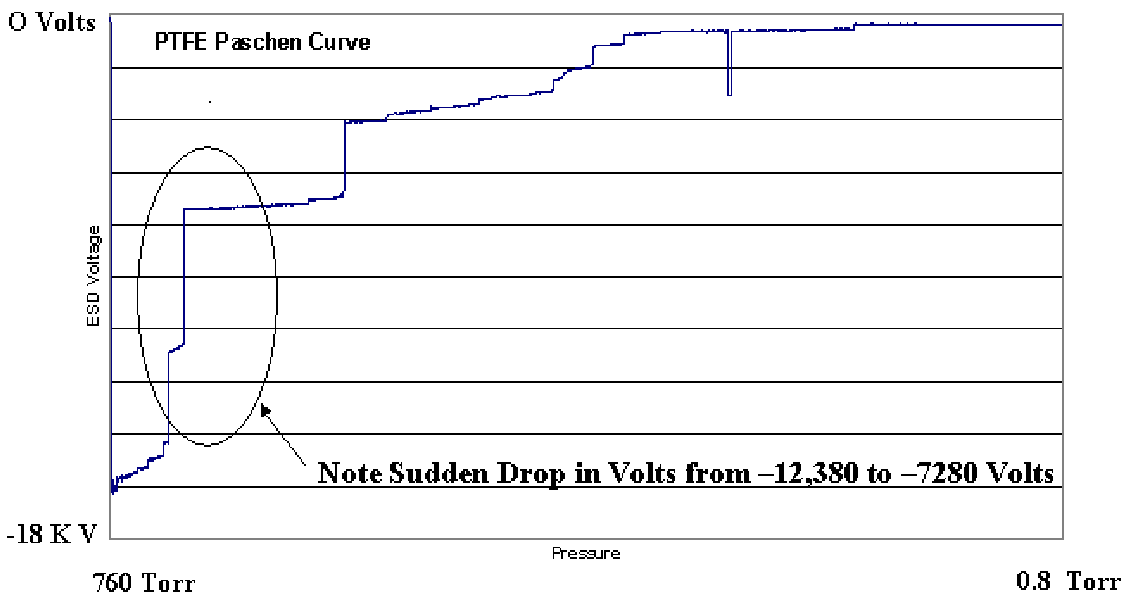

Figure 2: The Paschen curve for PTFE

The data shown in figure 3 was taken at 2 torr and shows the breakdown that occurs on an aluminum plate being charged by a high voltage power supply. The aluminum plate had geometry similar to the test samples but was buried into a PTFE plate so that it was flush to the surface in an attempt to reduce edge effects. The power supply voltage was slowly raised to the point of breakdown due to Paschen effects. The power supply curve is shown along with the voltage observed by the detector head. It is to be observed that the detector head had a complete breakdown to saturation at 736 volts.

V. Temperature Tests

Temperature tests done by the robot confirm previous testing done and reported by this author at the 19th Mr. Clean Conference using the first version of the ESD Robot. Figure 4 shows the effects of temperature on the electrostatic performance of an anti-static polyethlene material when the relative humidity is held constant at 45%. The samples were all acclimated at 45% relative humidity for 24 hours prior to testing.

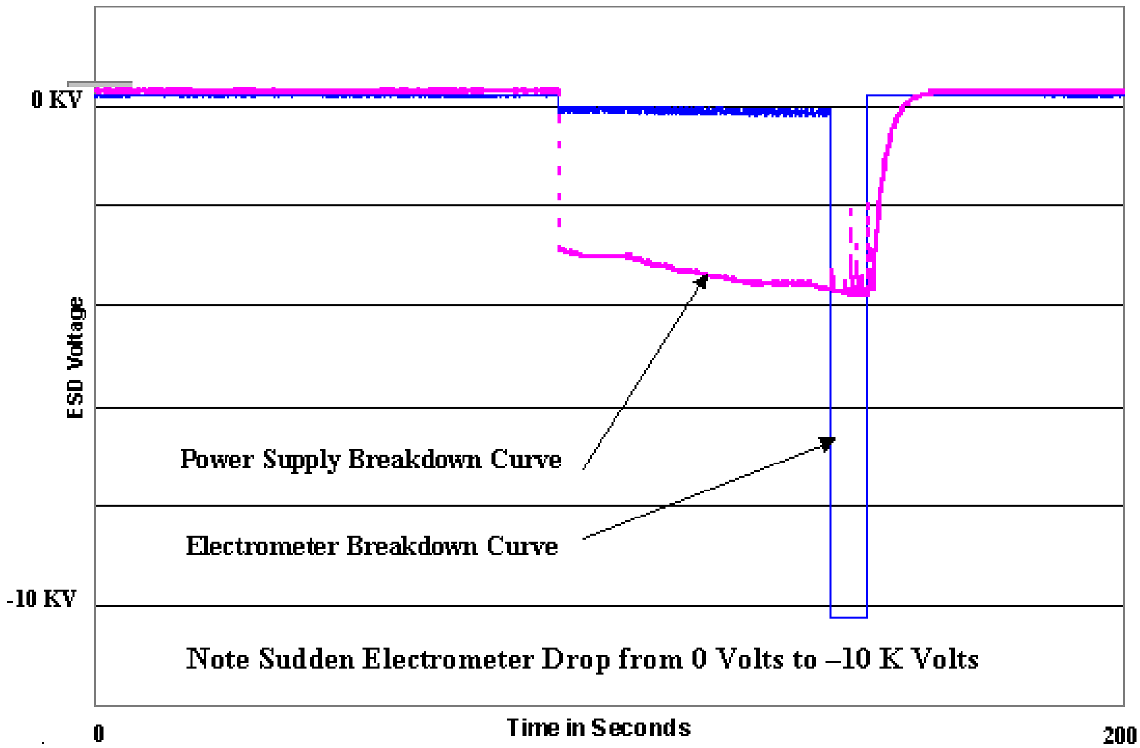

Figure 3: Aluminum plate voltage breakdown at 2 torr

Pressure (Torr)	**Paschen Voltage** (Howell)	**PTFE**	**Chlorinated Polyethylene-Nylon**	**Antistatic Nylon**	**PVC/Polyester**	**PCTFE***
0.6	538 volts	8960 volts	1640 volts	1280 volts	840 volts	5480 volts
2.0	1195	2220	9280	130	13350	2250
5.0	2370	1640	3300	2920	10680	-590
100	26,000	-3600	4460	5880	1380	-5200

*polychlorotrifluoroethylene

Table 1: Low pressure test results

VII Low PressureTest Results

The test results under low pressure are reported in table 1 above.

VIII Discussion of Test Results

From the data of table 1 it is observed that there are many voltages at 0.6 torr, 2.0 torr, and 5.0 torr that exceed the measured Paschen voltage for a metal plate. This was observed many times during this experiment in repetitive tests as well as additional data not included here. To this author it would seem the best explanation would be that each individual material, including insulating materials or those in between these two extremes have their own Paschen voltage. This Paschen voltage is closely related to the geometry of the environment and readily changes with regard to distance, pressure, and geometry.

The data shown in the graph of figure 2 indicate that the voltage drop on PTFE is not a smooth curve but rather that the voltage drops in sudden energy releases and apparently at random times. The data displayed in figure 3 show two curves from a dual trace oscilloscope. These display the detector head voltage on one trace and the actual voltage applied to an aluminum plate on the other. From this display it is observed that the detector system responds immediately to the breakdown of voltage due to Paschen effects.

Figure 4 shows that for an anti-static polyethylene as the temperature is increased the peak voltage increases little but the decay time is increased significantly. Additional tests on other materials not included in this study show that not all materials obey the trend shown in figure 4. Additional information on the temperature effects on the electrostatic properties of thin films can be obtained from the author. These studies with the robot continue at this time.

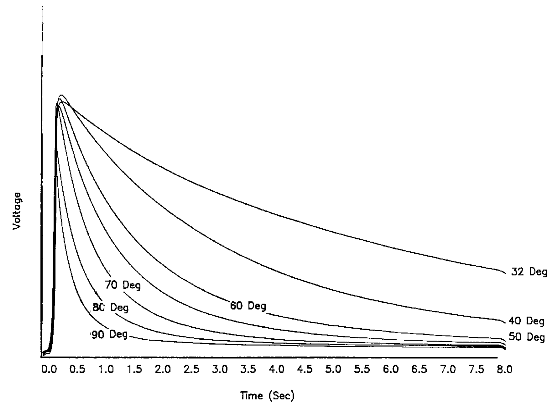

Figure 4: Temperature curves for an anti-static polyethlene

IX. Conclusions

Paschern voltage is the regulator of the maximum surface voltage that can generally be developed on a surface at specific low pressure conditions. While the Paschen voltage acts as the maximum voltage buffer of surface voltage, the data of this study indicates that each insulating material may have its own Paschen voltage. This insulating material Paschen voltage may be significantly larger than that for a metal under identical circumstances. This study indicates that under a dropping pressure where the paschen voltage is being approached, the voltage change is not smooth but rather sudden, perhaps as an arc. Arcs were observed to occur in the chamber at random times when observation was possible. This sudden voltage drop and energy release could be a safety concern in certain environments where electrical arcs are hazardous and there are rapid pressure changes such as launch into orbit.

An important conclusion that may have impact upon space and planetary exploration is indicated in the data that insulating materials may carry much larger surface voltages than was previously believed. Instead of being voltage limited by the Paschen voltage of metals the insulators each seem to have their own Paschen voltage which may be much higher than that of metals.

X. Recommendations

This report provides sufficient data to warrant further studies of low pressure and low temperature effects on the electrostatic properties of thin films and other materials. These studies have important mission success and safety implications for the aerospace industry. Certainly materials that are to be used in space applications should be tested at low pressures, at hard vacuum, and at low temperatures to determine the electrostatic properties under these conditions. Data on a select group of 50 thin films will be published by the KSC EMPL within one year. The data will include the measured electrostatic properties at low pressures and at low temperatures.

Acknowledgements

The author conceived the original idea, developed the conceptual plans and oversaw the detailed design for this robot. Theis Boessenkool, an engineering summer student at the KSC NASA EMPL, did the detailed design. Peter Richiuso of the KSC NASA Laboratories made some changes to these plans, built the operating robot and helped this author gather all data in this report.

Continual repairs due to electrical arcing to very sensitive electronic detectors and components were required. Equipment programs were needed in the operation of the robot and in the data analysis and display. Leon Davis, Larry Ludwig, Mike Spates, Larry Batterson, and Jon Bayliss, all of Spaceport Engineering and Technology at the NASA John F. Kennedy Space Center, were all instrumental in the success of this report and gave generously of their time in this effort.

Dr. Carlos Calle and Dr. Charles Buehler were a great resource of scientific information for this study.

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